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## PROBLEM-SOLVING OR PRACTICE IN THINKING. III<sup>1</sup>

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*Synopsis of preceding articles.*—The preceding discussion consisted of two parts, (I) An account of the place of problem-solving in everyday life, and (II) two sample lessons from the University of Chicago Elementary School. These depicted (a) pupils in the seventh grade debating the possibility and desirability of increasing America's sugar production, and (b) kindergarten pupils engaged in designing and constructing cardboard grocery stores. The present article will continue the sample lessons constituting section II of the discussion and then introduce section III on "how great problem-solvers think."

### C. SECOND GRADE: HOW TO DRESS AN ARAB DOLL

*Relation to course in community life.*—The study of the pupils' immediate environment which we found illustrated in the kindergarten lesson on grocery stores is followed in the first grade by a study of *farm* life and *Indian* life. These social types enrich the pupils' ideas of human wants and needs and of means of meeting these. In the second grade another strategic type of civilization is encountered in the study of primitive *shepherd* life.<sup>2</sup> Here the Arabs of the desert were being studied when the lesson which we shall describe was observed. The lesson occurred after the class had been studying Arabs for some time. On the sand table the children had made a desert, sand hills, and camel tracks, and had planted some miniature palm trees. On the blackboard along one side of the room were pictures of deserts, sand hills, and several camels. The teacher was Miss Mary Cameron.

*Conversation reported to illustrate details of technique.*—In describing this lesson we shall report more of the language used by the teacher and pupils in order to give a more detailed impression of the mental activities of the class, and of certain details of the

<sup>1</sup> This is the third of a series of four articles on this topic.

<sup>2</sup> For a full description of the study of shepherd life in this grade, see the *Elementary School Journal*, XVII (February, 1917), 411-16.

teacher's technique. Only a part of the total conversation of the pupils and teacher is reproduced, but enough is given to illustrate the conversational method of teaching. To assist the reader in following the conversation, the teacher's part is printed in italics.<sup>1</sup>

*Problem for the day.*—In the teacher's mind, the problem for the day was a study of the dress of the Arabs. The fundamental aim was to clarify and enlarge the ideas of the children concerning costumes. In the minds of the children, it was dressing dolls to people their desert.

*Procedure:* (1) *Children suggested several things that needed to be done.*—"We have finished our oasis and desert. What shall we do today?" asked Miss Cameron. The children replied, "Make some camels." "Make some Arabs." "What Arabs would you like to make?" "Some traveling Arabs." "We can make some tents, too," said one child. "How many Arabs shall we make?" "Twelve." "But," said the teacher, "our sand table is not very large." "Let's make two tents and two families," came from a little girl. "How many do you want in your family?" "The father, the mother, and a little boy or a little girl." "All right," said Miss Cameron, "or there might be both a little boy and a little girl. Now, here are the dolls you brought me. Which shall we choose for the father?" One doll was chosen. "What shall we do next?" "Make his clothes?" "Yes, but what must we do before we actually make the clothes? What does your mother do before she makes you a dress?" "She cuts a pattern." "Yes, and what else?" "She measures me." "Yes, and what else?" It was then decided that the clothing must be planned before it could be made. The planning followed.

2. *Teacher focused attention on planning clothes for father doll.*—"What clothes shall we need to make for the father?" asked Miss Cameron. "A turban." "A robe." "A sash." "Weapons." Then someone else suggested sandals. "How can we make sandals?" came from a little girl. "We will leave that for another time," replied the teacher. "What else shall we need for the father?"

<sup>1</sup> Again I am indebted to Miss Mildred Harris, who took shorthand notes, for a description of this lesson. I have inserted the paragraph headlines.

"A shawl." "Why does an Arab wear a shawl?" "It is so cold at night."

3. *Summary of suggestions by children.*—"Who can tell me everything that we shall need to make for the father?" A child volunteered, "A sash, a robe, a turban, sandals, and a shawl." "Let's look at some pictures," said the teacher. "Notice carefully what these Arabs have on. Think about how we can make the clothes for the father." The children then all looked at the pictures.

4. *Attacked problem of making a robe.*—One little girl exclaimed, "We will have to have a robe." "What will you need to make a robe?" Then, from various children came "Scissors." "Thread." "Red cloth." "A ruler." "Needles." "White cloth." "All right," said Miss Cameron, "here is some cloth. Who has a suggestion for making the robe?"

5. *Boy experimented on robe.*—A boy went up to the table and taking a small piece of white cloth, cut a hole in it, and slipped it over the head of the doll. The teacher asked him to hold it up so that the others might see it.

6. *Criticisms and alternative suggestions by other children.*—A couple of the children objected to the looks, saying, "It is too short." "How long should it be?" "It should come below the knees." "Oh, it should come clear to the heels," from another pupil. "What else can you suggest about this robe?" "Robes are loose over the shoulder." "How could we make a robe that way?" One boy said he would have a piece hang over each shoulder. Another wanted it to come to a point in the back. Another wanted it fastened in some way. One said the hole for the neck was too large. "Why is it too large?" asked Miss Cameron. "It won't stay on the shoulder." "You could button it on," said one girl. "Who thinks he can make a better robe?" A girl tried. She held the doll up and said, "I would hold it together, this way, with a sash." "Is it all right?" asked the teacher. "No, it is not full enough."

7. *Subordinate problems arose: sleeves and sash.*—"Where are the sleeves?" asked a child. "Will someone show us how the sleeves might be fixed so that they will be right?" added the teacher. A girl pinned the sleeves. "Do you think that is better?" "No,"

came from several. Finally, the children got the sleeves pinned a little more to their taste. "*What could we use for a girdle?*" queried Miss Cameron. "A piece of cloth." "A piece of tape." "Paper." "*I am thinking of something that your mothers are using a great deal these days,*" said she. "Yarn!" A piece of yarn was selected and wound around the doll. "*Do you like the side of this robe? Shall we tomorrow make the side this way?*" "No," said a child, "we must sew it." The teacher then had them examine a seam of a little child's dress. They decided the edge of the seam must be straight and not left rough. "We can tuck it in," said a child, meaning French-seamed.

8. *Devising a turban.*—"What else can we make for the father?" "A turban." "All right." A girl then took a piece of white cloth and tried to make a turban. She made it look about like a veil, hanging down the back. "*Do you think it looks like a turban?*" "No, it should not hang down," said a boy. "*You try it,*" said the teacher. The boy got up and tore a very narrow strip off and wound it around the head of the doll. The result was a pretty good turban. "Looks like the father had a sore head," said one child.

9. *Standard for comparison presented by teacher.*—"Compare it with a picture of a turban," said the teacher, producing a picture of a man with a turban. "Pretty good," was the general verdict. But some were not satisfied with the sore-head appearance. "*See if you can improve upon it,*" to a little girl. The latter tried to make a turban by first winding it around her finger. She failed, and then wound the strip around the doll's head as the boy had done. However, she took a broader strip. Some liked it better. "*Why do you think it is better?*" "It covers the head better." "It is more the shape." "*Is the turban finished?*" "No, a cord should be around it." "*You come and put a cord on.*" A boy put a bit of yarn around the turban for a cord. "It should be the same color as the sash," came from a girl. "*That might look better,*" said the teacher.

10. *Problem for next day.*—"Tomorrow we shall make a shawl. If any of you have anything at home that you think you would like to use to make your shawl, it would be nice to bring it to school." Then

different children told of what they could bring. "We must make a collar. Men wear collars," came from one child. "*Do Arabs wear collars?*" They decided not.

11. *Child off the track.*—One girl arose and very earnestly began telling how a doll she had was dressed. It was brought from abroad. It was a French doll. The teacher listened a moment and then asked, "*But what kind of people are we talking about?*" "Arabs" came in a chorus. "*Bring your things for a shawl tomorrow, and we shall finish dressing the Arab father.*" Thus ended the lesson.

*Conversational method prevails in problem-solving discussions.*—As indicated above, the conversational form in which this second-grade lesson is described helps us to get a clearer idea of the conversational spirit that prevails in a problem-solving discussion lesson than we derived from the seventh-grade lesson on sugar production or the kindergarten construction lesson. It is important to realize, however, that in both these lessons the same informal conversational give-and-take between teacher and pupils prevailed. At the same time, in all the lessons, we feel that the teacher is a very definite, stimulating, and guiding force. She keeps the pupils' minds actively directed along educative lines so that they are acquiring important ideas at the same time that they are acquiring training in the reflective solution of problems.

#### D. FIFTH GRADE: STANDARDIZED SHORT GEOGRAPHY PROBLEMS ON THE BRITISH ISLES

*Transition from simple primary construction problems to technical scientific problems of higher grades.*—As a final example of problem-solving lessons in the elementary school, we shall present one from a fifth-grade class in geography. This lesson will show the transition from (a) the simple construction problems arising out of social needs which we have illustrated from the kindergarten and second grade to (b) the more complicated, technical problems of the upper grades which we illustrated by the problem of the United States increasing its sugar production, and which brought in such technical issues as the number of growing days required by sugar cane, the cost of labor, competing crops, and the question of a tariff on sugar. In this fifth-grade lesson we shall find the children dealing with certain simple technical matters such as the tides in navigable

rivers and the use of a scale of miles and of the directions, east, west, north, and south, in reading a map.

*London problems. How is London influenced by the Thames? Dialogue.*—Under the direction of Miss Edith Parker, the children in the fifth grade had taken up the study of the British Isles. They had begun the study of London shortly before the lesson which we shall describe. In order to give the reader further notions of the conversational technique of problem-solving discussion lessons, we shall present most of this lesson in dialogue form as reconstructed from rapid memoranda which I made during my observation. We shall use capital "T" to designate the teacher's remarks, which are printed in italics, and capital "P" to designate the pupils' remarks. Occasionally, where I caught the name of the pupil, I have used it. Much of the dialogue is omitted, but enough is given to illustrate the procedure. The teacher's remarks are numbered in order to facilitate discussions of the lesson.

*The lesson.*—After the children were seated and quiet reigned, the lesson proceeded as follows:

*Introductory.*—(1) T: "*How many can now see London on the map without looking at the latter?*" (The pupils held up their hands as Miss Parker waited a moment.) "*About how far from the mouth of the river is it? Look at your maps and, using your scale of miles, work it out.*"

P: "I say it is exactly forty miles, because it is double the distance across the Strait."

Another P: "I say it is just thirty-five by the scale."

(2) T: "*Your differences may be due to your choosing different places as marking the mouth of the river. Measure clear out to the place marked North Foreland.*" (The children then discussed and decided upon the distance.)

(3) T: "*How could such a large seaport as London develop so far up the Thames River? Put up your hands when you are ready. I want to see many of you ready before I call on anybody.*" (She then waited about one-half minute.) Martha: "Because of the tides."

(4) T: "*How do the tides help?*" Martha: "I don't know how." Julian: "The tides help to make it a great port. They let the boats come in."

(5) T: "*How many agree with Julian?*" . . . (A brief discussion followed which brought out the fact that the *high* tides make the river deep enough to let the *big* boats come up. The teacher told of *large* vessels waiting at Gravesend for *high* tide to ascend the river and of "locked" docks being used to keep these vessels afloat during *low* tide.)

*Written questions presented.*—T: "*We have here (indicating the blackboard) some questions for you. Some you can answer easily and others you will have to think out. Will you read the first question and answer it, Ellwood?*" (The full list of questions is printed in the footnote below.<sup>1</sup>)

*First written question.*—Ellwood read, "How is the city situated with regard to the Thames? See map on page —." (The pupils turned to a small map of London. Ellwood's answer was vague.)

Another P: "The map shows the river running right through London. They have a Hyde Park!" (These children lived in Hyde Park of Chicago.) Another P: "The river looks awfully twisty here—not straight."

(6) T: "*What other points about London and the Thames do you find from this map?*" Various P: "Many parks." "Victory roads." (Other irrelevant answers.)

(7) T: "*Do those have anything to do with the Thames? It is not a good answer unless it shows how London is related to the Thames.*" (The pupils now held better to the question.) P: "It has many bridges." Another P: "The city extends far along the river, both north and south of it."

<sup>1</sup> The questions for Miss Parker's lesson on London were written on the blackboard as follows:

#### LONDON

1. How is the city situated with regard to the Thames? See map on page —.
2. What determined the location of London Bridge?
3. In which direction are the docks from the bridge and why?
4. How does the location of the docks affect the location of the factories in London?
5. How does the location of the factories affect the location of the living quarters for workers?
6. Where would you expect the business section to be?
7. Where would you expect the wealthy residence section to be?
8. Why has London become such a great city?

(8) T: "*How long is London?*" P: "About eighteen miles." (Various other answers to the first question were developed.)

*Summing up first question.*—(9) T: "*Now let us sum up what we have found in answer to the first question.*" (As the pupils enumerated their points, the teacher wrote them on the board in outline form, thus:

1. On both sides
2. Winding
3. 20 miles
4. Bridges

*Second question.*—P (reads from blackboard): "What determined the location of London Bridge?"

(10) T: "*If you had visited the Thames River and the site of London before the city was built, you would have seen something like this.*" (Then she drew on the board a diagram of the river and described the location of the highlands and the low marshes and swamps.) "*When the people wanted to build a bridge over the Thames, where would you say it would be, judging from this diagram?*" (The children were very quiet and considerably puzzled.) P: "Right here where it was narrowest." (Pointing at a certain point on the diagram.)

(11) T: "*My diagram is not exactly right if the river seems narrower to you at this point. I will change it because the river is not really narrower there. What do you think, Frank?*" Frank: "I should say right here, near the highland; one could easily get at it." (The pupils now became quite active in agreeing or disagreeing with Frank.)

P: "I agree with Frank, but I want to ask a question first. (He then went to the board and asked something about the depth of the river. He quickly decided his own idea was not a good one and retired to his seat. After the hour, Miss Parker said this boy was an impulsive thinker, and that his self-checking in this case really represented growth on his part. As a rule the class or teacher had to check him.)

(12) T: "*Now let's finish the discussion of Frank's plan before we take up another.*" (Several pupils talked, largely in terms of carrying timbers, easy access to one bank or the other, etc.)

(13) T: "*How many are pretty well convinced now that this would be the best place for the bridge?*" (Many hands were held up.) "*Do you have something new to offer, Oliver?*" Oliver started to talk along the same line.

(14) T: "*Yours is just a part of the same general argument. . . . Are you ready to know what really happened? . . . This is the place (pointing at the diagram) that the bridge was built. Here the river swings in against the cliff. It was the first place as they came up the river, where they could find a good place to build a bridge. . . .*" (She then sketched in the bridge on the diagram.)

*Third question.*—(15) T: "*Our next question, Jack.*" Jack read: "In which direction are the docks from the bridge, and why?" P: "That's the easiest question yet. Seaward."

(16) T: "*Yes, that's a good answer, but I mean what cardinal direction, north, east, south, or west.*" Various P: "North." "West." "East."

(17) T: "*Isn't it strange that you can't tell me from this small map whether the docks are east, west, north, or south of the bridge. . . . What is the difficulty?*"<sup>1</sup> (The period was now at an end, so this problem, together with questions 4, 5, 6, and 7, which dealt with the location of factories and residence sections and the reasons for the greatness of London, were left for the next lesson.)

*Growth of diagram summarizes results of thinking.*—At the end of the discussion of all the questions, the simple diagram of the bends in the river with which they began had been supplemented with answers from the later questions until it showed the docks for various kinds of merchandise, factories of various kinds, residence districts for poor and rich, etc.

*Points of technique briefly noted.*—As in the case of the first two lessons which we described, it will be helpful to note certain general characteristics of this London lesson preliminary to our organized discussion of technique which is to follow in section IV. Briefly stated these characteristics are the following:

1. *A deliberate pace prevailed.* For example, in the paragraph numbered 3 in the dialogue, Miss Parker waited about one-half

<sup>1</sup> Miss Parker explained to me later that while the children had attained fair skill in reading directions on large colored maps, they needed more drill in applying the same principles to small city maps.

minute after saying, "Put up your hands when you are ready. I want to see many of you ready before I call on anybody."

2. *Evaluation by the pupils was encouraged.*—Among Miss Parker's favorite remarks are, "Do you think that is a good point?" "Do you agree with that?" "Is that a good argument?"

3. *Standards of good thinking were taught the pupils.*—Examples occur in paragraph 7, where she emphasized holding to the question by saying, "It is not a good answer unless it shows how London is related to the Thames," and in paragraph 12, "Now let's finish the discussion of Frank's plan before we take up another," and in paragraph 14, "Yours is just a part of the same general argument."

4. *Summing up the discussion was periodically attended to.*—The best example given above is in paragraph 9, where the answers to the first problem were reviewed by a pupil and written on the board by the teacher as a few concise numbered points.

5. *The thinking was kept organized* by four devices, namely (a) writing the principal questions on the board; (b) holding to the main point of each discussion as described above under 3; (c) summing up periodically, as described under 4; and (d) by building upon a diagram the important data, suggestions, and conclusions as they came along.

*Experimentation in grading problems and technical data and activities for fifth-grade geography.*—Finally, before turning to section III of the discussion, in which we shall inquire how skilled problem-solvers think, we may, as a further preliminary to our general conclusions about technique in section IV, present Miss Parker's own memorandum concerning experimental work in organizing problem-solving lessons in the middle grades. These points she gave me for presentation to my class of teachers before we observed one of her fifth-grade lessons. She wrote as follows:

Experimental work in teaching geography in this fifth grade is being done in order

1. To determine what problems are of the right difficulty for children of this age; in other words, to grade problems.

2. To determine the degree of subdivision of problems necessary and the definite steps in solution that need to be indicated for children of this age.

3. To grade the map reading, text reading, picture reading, and statistics reading that is motivated by these problems.

4. To devise means of establishing thoroughly those principles of interpretation of maps, pictures, statements, and statistics that can be established in this grade.

5. To devise means of helping children of this age to work independently and to check their own inferences. (Written directions are being used at present in an effort to lessen dependence on the teacher.)

6. To devise means of getting reactions at each step from *each* individual rather than from one or two. This is a vital matter in the fifth grade where basic interpretation habits are being formed. It is a matter that is often neglected where the problem-solving method is dominant.

*Conclusion of discussion of actual lessons of section II. Transition to section III.*—This will conclude our long section II, in which we have presented, in considerable detail, four problem-solving lessons in order to give the beginning teacher a vivid idea of this type of teaching as it is actually carried on in a progressive elementary school. The seventh-grade lesson on sugar and the kindergarten cardboard construction lesson gave us general notions of the organization of such lessons. The conversational data given in the second-grade Arab lesson and the dialogue of the fifth-grade London lesson brought us more intimately into the conversational give-and-take between teacher and pupils that characterizes problem-solving discussions. In all the lessons, we found the teacher aiding the pupils to get the problem clearly in mind, to make and evaluate suggestions, and to keep their thoughts moving actively along some particular educative line. We found many of the pupils alert and active in suggestion, sometimes keenly critical, and gradually developing in ability from the kindergarten, where they decided how many hinges a door needed, to the seventh grade, where they were ready to consider whether a tariff should be placed on sugar in order to encourage home production. In Miss Parker's final memorandum we found a skilled teacher especially concerned about the issue of grading problems in the middle grades so as to adapt them in general to this grade of pupils, and to give even the slow pupils practice in thoughtfully using the technical tools of problem-solving that are used by scientific specialists in geography. We shall now turn to a description of how problem-solving thinking is done by skilled thinkers, notably great scientists, such as great geographers, astronomers, etc.

## III. HOW SKILFUL PROBLEM-SOLVERS THINK

*Need to analyze skills to determine methods.*—In discussions of the teaching of any form of skill such as handwriting or reading, we find it necessary to determine how skilful performers behave, e.g., how skilful handwriters and readers perform, in order to determine how to give pupils similar skill. In the case of handwriting, for example, we find that careful laboratory experiments have been necessary in order to prove that in much expert handwriting the letters are made predominantly with finger movements instead of arm movements. In the case of reading, we find that a variety of types of reading skill can be distinguished, and that many tests and laboratory experiments have helped us considerably in understanding how skilled reading is done and how to train children to be skilful, resourceful readers.

*Need similar analysis of skill in problem-solving.*—Similarly, in the case of problem-solving, we need a clear understanding of how skilful problem-solvers think in order to practice pupils in doing the same type of thinking. As in the case of handwriting and reading, so in the case of thinking, a number of erroneous ideas have prevailed concerning the nature of the processes of skilled performers. We shall not have time or space, however, to discuss these mistaken notions here, but shall turn our attention immediately to an account of the methods of thinking and inquiry used by some of the greatest thinkers, namely, by great scientists as these are described by W. Whewell in his *History of the Inductive Sciences*.<sup>1</sup>

*Biographies of certain great scientists reveal methods of thinking.*—Whewell had made a profound study of the methods and results of most of the great scientists up to his time. In connection with his account of the great astronomer, Kepler (1571-1630), he

<sup>1</sup> Whewell's work, published in 1837, is an excellent exhibition of careful English scholarship. T. H. Huxley, in *The Advance of Science*, p. 74, characterizes Whewell as a man of "great acquirements and remarkable intellectual powers." It would be well if more persons would secure their ideas of scientific method from such works as Whewell's instead of from Francis Bacon's false theories. In contrast with Bacon's ignorance of actual scientific investigations and ridicule of the methods of his great scientific contemporaries (such as Copernicus) Whewell proceeded to derive correct notions of the nature of scientific thinking by an examination of the methods actually used by great scientists in their work.

describes methods of scientific study and research in general, and, at the same time, gives an interesting account of Kepler's peculiar traits.

*Accounts should include failures as well as successes. Whewell's description.*—Kepler's investigations furnish especially good material from which to determine how a great scientist thinks because he left accounts of his whole process of inquiry, including his incorrect ideas and unsuccessful endeavors as well as the correct ones. With these accounts in mind, Whewell wrote the following discussion of how great scientists discover new truths and solve great scientific problems (I, 291-92):

*Bold guessing.*—Advances in knowledge are not commonly made without the previous exercise of some *boldness and license in guessing*. The discovery of new truths requires, undoubtedly, minds careful and scrupulous in examining what is suggested, but it requires, no less, such as are quick and fertile in suggesting. What is invention except the talent of rapidly calling before us many possibilities and selecting the appropriate one? It is true that when we have rejected all the inadmissible suppositions, they are quickly forgotten by most persons, and few think it necessary to dwell on these discarded hypotheses, and on the process by which they were condemned, as Kepler has done.

*Reasoning on many errors.*—But all who discover truths must have *reasoned upon many errors* to obtain each truth; every accepted doctrine must have been one selected out of many candidates. In making many conjectures which on trial proved erroneous, Kepler was no more fanciful or unphilosophical than other discoverers have been. *Discovery is not a cautious or rigorous process in the sense of abstaining from such suppositions.* But there are great differences, in different cases, in the facility with which guesses are proved to be errors and in the degree of attention with which the error and the proof are afterwards dwelt on. Kepler certainly was remarkable for the labor which he gave to such self-refutations and for the candor and copiousness with which he narrated them; his works are in this way extremely curious and amusing and are a very instructive exhibition of the mental process of discovery. But in this respect, I venture to believe, they exhibit to us the usual process (somewhat caricatured) of inventive minds—they rather exemplify the *rule* of genius than (as has generally been hitherto taught) the *exception*. We may add that if many of Kepler's guesses now appear fanciful and absurd, because time and observation have refuted them, others, which were at the time equally gratuitous, have been confirmed by succeeding discoveries in a manner which makes them appear marvelously sagacious, as, for instance, his assertion of the rotation of the sun on axis before the invention of the telescope. Nothing can be more just, as well as more poetically happy, than Kepler's picture of

the philosopher's pursuit of scientific truth, conveyed by means of an allusion to Vergil's shepherd and shepherdess.

Coy yet inviting, Galatea loves  
To sport in sight, then plunge into the groves;  
The challenge given, she darts along the green,  
Will not be caught, yet would not run unseen.

*Devising tests of false suppositions.*—We may notice as another peculiarity of Kepler's reasonings the length and laboriousness of the processes by which he discovered the errors of his first guesses. One of the most important talents requisite for a discoverer is the *ingenuity and skill which devises means for rapidly testing false suppositions* as they offer themselves. This talent Kepler did not possess; he was not even a good arithmetical calculator, often making mistakes, some of which he detected and laments, while others escaped him to the last.

*Willingness to abandon false hypothesis.*—But his defects in this respect were compensated by his courage and perseverance in undertaking and executing such tasks; and, what was still more admirable, he never allowed the labor he had spent upon any conjecture to produce any reluctance in *abandoning the hypothesis as soon as he had evidence of its inaccuracy*. The only way in which he rewarded himself for his trouble was by describing to the world, in his lively manner, his schemes, exertions, and feelings.

*Scientists' method of solving problems. Bold guessing; erroneous guessing; devising tests; abandoning errors.*—Careful reading and study of the above quotation will give us most of the ideas that we need to understand the thinking processes in problem-solving. We may list them briefly as follows:

1. Bold guessing as the basis of fertile suggesting.
2. Erroneous guessing, "All who discover truths must have reasoned upon many errors to discover each truth."<sup>1</sup>

<sup>1</sup> Huxley (*op. cit.*, p. 33) supports Whewell's statement of the place of guessing or conjecturing in careful scientific thinking in the following words:

"It is a favorite popular delusion that the scientific inquirer is under a sort of moral obligation to abstain from going beyond that generalization of observed facts which is absurdly called Baconian induction. But anyone who is practically acquainted with scientific work is aware that those who refuse to go beyond fact, rarely get as far as fact; and anyone who has studied the history of science knows that almost every great step therein has been made by the "anticipation of nature," that is, by the invention of hypotheses, which, though verifiable, often had very little foundation to start with; and, not unfrequently, in spite of a long career of usefulness, turned out to be wholly erroneous in the long run.

"The geocentric system of astronomy, with its eccentrics and its epicycles, was an hypothesis utterly at variance with fact, which nevertheless did great things for the advancement of astronomical knowledge. Kepler was the wildest of guessers. Newton's corpuscular theory of light was of much temporary use in optics, though nobody now believes in it."

3. Skill in devising means of testing the truth of guesses.
4. Willingness to abandon an erroneous guess or hypothesis.

*Kepler succeeded though handicapped by slowness and by poor calculations.*—In addition to these characteristics of reflective thinking as found in the work of great scientists, it is interesting to note that Kepler succeeded wonderfully in spite of certain personal handicaps. For example, “He was not even a good arithmetical calculator, often making mistakes, some of which he detected and laments, while others escaped him to the last.” When one recalls what an important factor mathematical precision is in modern scientific method, he can appreciate what a handicap Kepler labored under. Moreover, he was not *rapid* in devising means of testing his suppositions, but he compensated for this lack “by his courage and perseverance in undertaking and executing such tasks.” In general, these characteristics of Kepler suggest that a person, for example, a pupil, may be a very competent thinker and, in the long run, very successful in solving problems, yet be very slow and laborious in his methods of criticism and verification.

*Scientific biographies reveal “how we think.”*—Such accounts as Whewell gives of the personal efforts of scientific workers to solve problems help us to understand the actual mental processes involved in skilled thinking. On the basis of this understanding, we can proceed to give pupils practice in doing similar thinking. In recent years the psychological writings of William James and John Dewey have especially emphasized the nature of these thinking processes. From their discussions educators may derive help in understanding “how we think” and how to practice pupils in thinking. In the next article, we shall present briefly Dewey’s description of “how we think” and then conclude the series of articles with section IV on “rules for practicing pupils in problem-solving.”

[To be concluded]